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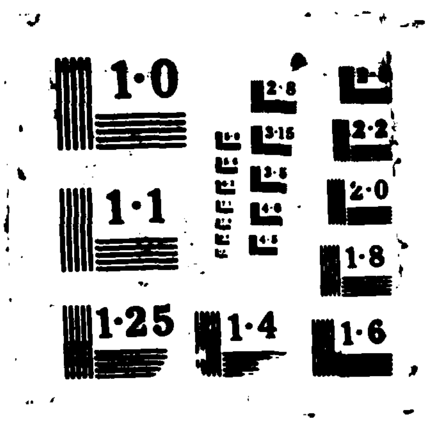
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A STUDY OF THE INTERACTION OF LASER LIGHT WITH LIQUID PROPELLANT DROPS

RICHARD A. BEYER
LINDA C. MAAS

APRIL 7, 1987

US ARMY BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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The interaction of liquid propellant drops with the beam from a modest power carbon dioxide laser has been used to observe evidence of strong internal circulation and corresponding instability ot these drops. The drops appear to relax, but characteristic times may extend to as much as 0.1 sec. The drops are found to break up under relatively small perturbations when highly circulating. The implications in gun environments where interdrop collisions may occur shortly after drop formation, as well as the potential importance to possible research configurations, are discussed.

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TABLE OF CONTENTS

		Page
	LIST OF FIGURES	5
I.	INTRODUCTION	7
II.	APPARATUS	7
III.	OBSERVATIONS	7
IV.	DISCUSSION	10
V.	CONCLUSION	13
	ACKNOWLEDGMENT	14
	REFERENCES	15
	DISTRIBUTION LIST	17

LIST OF FIGURES

Figure		Page
1	Schematic of Experimental Apparatus	8
2	Complex Drop Formation Sequence. Shown are (a) drop still attached to the dropper, (b) larger drop breaking away from the dumbbell, (c–e) remaining liquid pulling together to form a smaller drop, and (f) final drops with diameters of about 270 μm and 200 μm	9
3	Photographs of a Typical Drop as Impacted by the Laser Beam	10
4	Drop-Laser Beam Interaction at Several Heights Above the Drop Maker. Shown are (a) both parts being affected when the laser beam is focused one millimeter above the dropper tip, (b) both still strongly affected with laser moved up to two millimeters above tip, and (c) at a height of four millimeters the smaller drop passes through unaffected after the larger is still strongly perturbed	11
5	Schematic of Drop Evolution and Hypothesized Circulation	12
6	Infrared Absorption Spectrum of LP 1845	12

I. INTRODUCTION

The basis for detailed understanding of the interior ballistics of liquid propellant (LP) regenerative guns is intimately tied to understanding the breakup of the injected LP into drops, and the ignition and combustion behavior of the liquid propellant throughout this process. The present study is an outgrowth of our program to measure the burning phenomena of individual LP drops under controlled conditions.

In our earlier reported studies,[1] drops of LP were introduced into a hot flow at atmospheric pressure for studies of pyrolysis rates and diagnostic development for higher pressure observations. In those studies, the drops were seen to balloon and explode after a relatively small part of the volume had been consumed. It was also noted that there was a clear relationship between the drop formation history and the time of microexplosion. This observation had been made earlier for multicomponent hydrocarbon fuels,[2] although without any parameterization or quantification. In the present studies, attempts were made to repeat some of our earlier experiments by heating with a carbon dioxide laser operating near 10.6 μm wavelength. The liquid propellants of interest, and their components, have sufficient absorption in this region to insure substantial heating of the drops. In addition to allowing heating rates to be varied over a wide range, heating with the laser allows the possibility of selectively depositing energy in various components of the liquid through wavelength selection. This study was also expected to provide valuable data for evaluation of laser heating of these materials in high pressure static chambers.

II. APPARATUS

Materials studied were hydroxylammonium nitrate (HAN) and LP 1845 (HAN, triethanolammonium nitrate, and water). Drops were formed from a piezoelectric drop making device which has been described in detail earlier. It allows the formation of reproducible drops on command at rates which can be varied from single drops up to a few hundred per second. Drop sizes studied were in the range from 50 to 400 micrometers in diameter. The laser used was a nominal 50 Watt flowing gas carbon dioxide laser operating at a few wavelengths near 10.6 μm. A 40 cm spectrum analyzer was used to characterize the emission wavelengths as a function of gas pressure and excitation current. Observations of the laser-droplet interaction were made with a microscope using a strobe light for back lighting to freeze the motion. Gas phase products were sampled with a 30 mℓ syringe and injected into an infrared absorption cell for analysis.

III. OBSERVATIONS

A schematic of the apparatus used for the majority of the reported observations is given at Figure 1. Using a 38 mm focal length lens, the multimode laser beam was focused to 0.4 mm diameter. Drops were injected into the focal region perpendicular to the laser beam. The main observation made here was that drops which had been formed in a complex mode of generation, such as shown in the sequence of Figure 2, tended to be strongly disturbed by the laser beam. Even at 8 Watts, which is an energy density of approximately

6000 watts/cm^2, the drops were subject to stresses that caused total breakup of the drop. A typical such interaction is shown in Figure 3. In contrast to the microexplosions observed in the convective heating, observations made with the laser power near the drop breakup threshold indicate that this breakup is the result of surface absorption of the laser energy, ablation, and subsequent impulse to the drop.

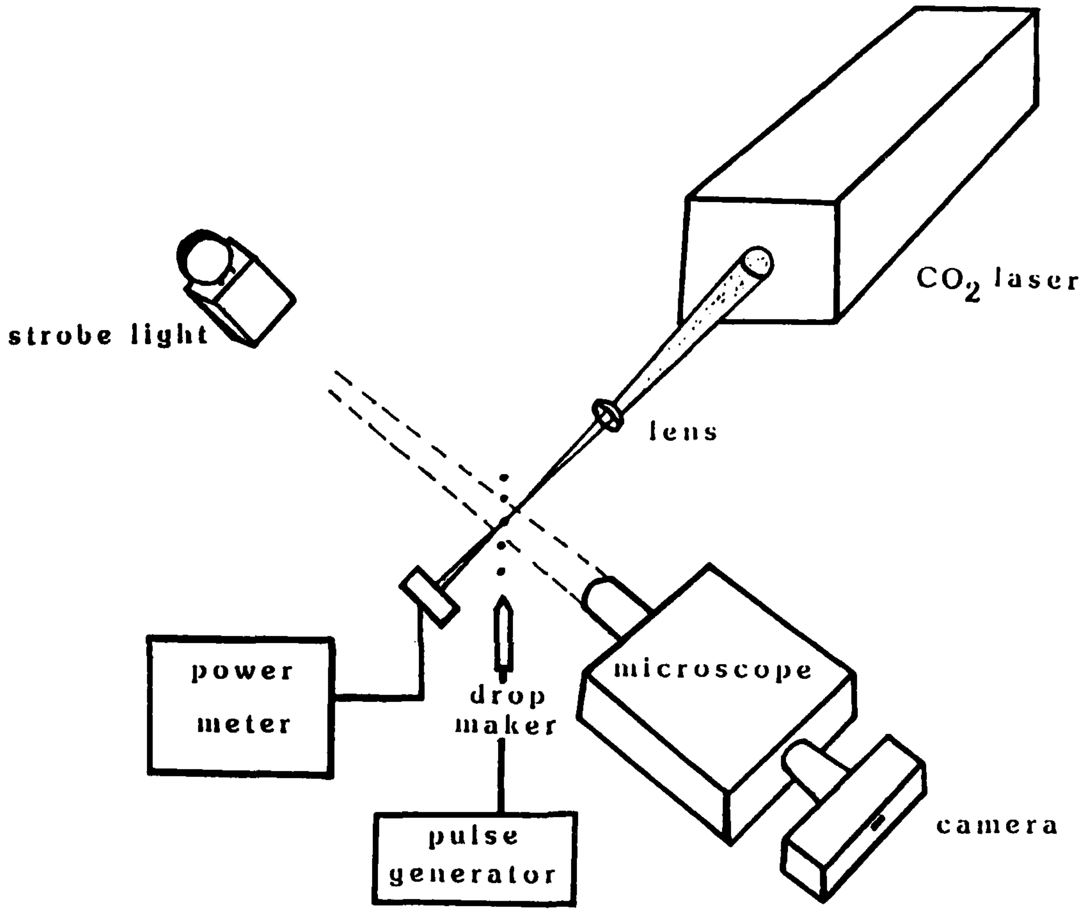


Figure 1. Schematic of Experimental Apparatus

As expected for materials with the high viscosity of these liquids, the drops relax in times which vary up to approximately 0.1 sec, but which are much shorter in most cases. A typical sequence of drop-laser interactions is shown in Figure 4. In that figure, drops are illuminated by the laser at distances of one, two, and four millimeters above the nozzle tip. As can be seen there, at the closest and intermediate distances, both drops are strongly affected. However, by the time the small drop has traversed the four millimeters to the last pictures, the small drop is sufficiently stabilized that it passes through the beam unaffected. This phenomenon has been observed in many diverse unstable drop formation configurations. While internally excited, small drops are at least equally affected by the laser light impact as are larger drops. After relaxation, the larger drops are more affected by

the laser beam than the small drops, which can often pass through the beam unaffected following a larger drop that is broken into a large number of smaller drops. Although there is great variability of the effect of the drop-laser interaction, as is expected for such events, in a typical example, a 165 μm diameter drop passing through the 8 watt laser beam was reduced to 90 μm diameter. The remainder of the liquid was in very small droplets and vapor.

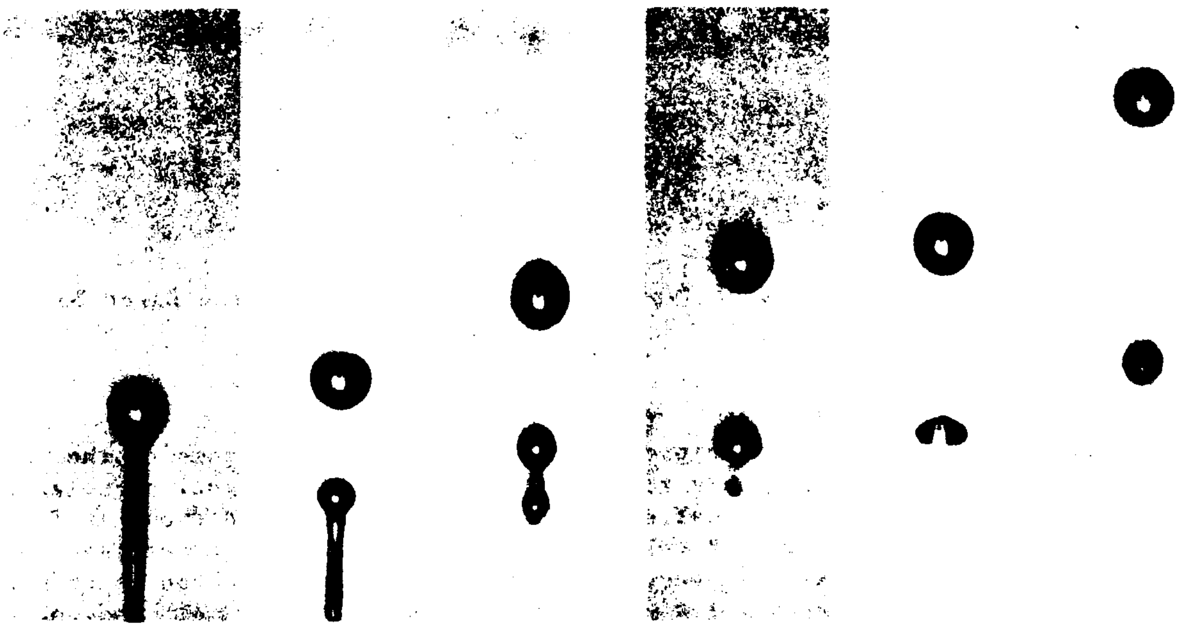


Figure 2. Complex Drop Formation Sequence. Shown are (a) drop still attached to the dropper, (b) larger drop breaking away from the dumbbell, (c-e) remaining liquid pulling together to form a smaller drop, and (f) final drops with diameters of about 270 μm and 200 μm

When traversing the laser beam, drops were also seen to give off a puff of dense vapor that resembled smoke. More vapor was observed when the interaction was more violent and the drop was broken apart. This material was sampled and analyzed with an Fourier transform infrared absorption spectrometer. The analysis was consistent with the vapor being composed of water.

Drops were also irradiated with the unfocused, 6-mm diameter beam almost colinear with the drop path. Although it was difficult to obtain stability and reproducibility with this arrangement, vapor trails were seen during the time the drops were in the beam. This vapor was not sampled; it had the same appearance to the eye as that sampled, as described above. There was no evidence of drop breakup under these conditions.

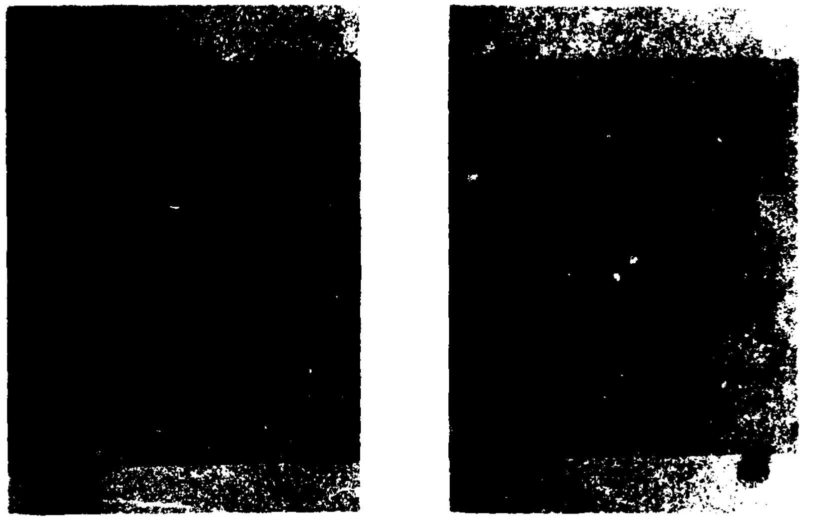
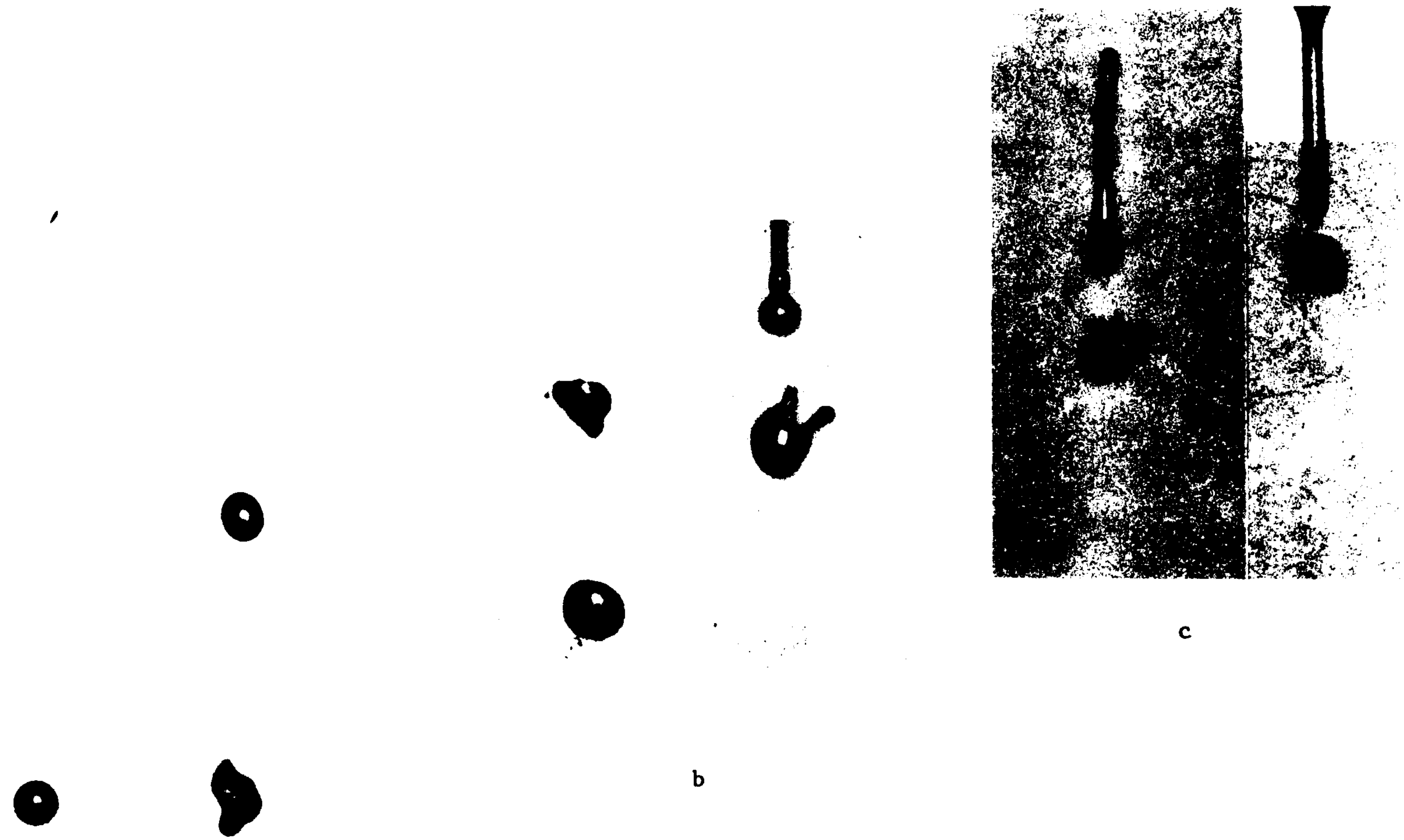


Figure 3. Photographs of Typical Drops as Impacted by the Laser Beam

IV. DISCUSSION

Our interpretation of the present observations is that some of the LP drops (the "unstable" ones) are formed with substantial internal circulation. A schematic diagram of a typical event for this occurrence is shown in Figure 5. Although this is drawn for only one of several possible geometries, the high surface tension makes it very common to form drops as dumbbells or with a long extension (as fine as a few microns in diameter) to the main body of liquid. The resulting contraction into a drop almost necessarily will result in a circulation pattern such as that shown. In this study it was frequently observed that two drops joined together often split with one highly excited and the other almost totally quiescent. It is our interpretation of these observations that the rapid internal circulation, combined with an impulse on the surface from laser driven ablation of material could cause drop breakup. Because of the high viscosity and the relatively low Reynolds numbers in this work, the circulation is damped in a fraction of one second.

Interaction of the drop with the laser appears to be a surface phenomenon. An infrared absorption spectrum of LP 1845 is shown in Figure 6, along with some of the major laser lines observed with our system. Although the analysis of the vapor suggests that the energy is being absorbed primarily by the water component, this absorption curve, and that of HAN, suggest that the other components could be involved. Attempts to change the dominant laser wavelength by varying the discharge characteristics resulted in no visible change in the observed phenomena. Following the absorption of the laser energy at the surface, the ablation of the surface layer causes an impulse to the drop. For a drop that has had sufficient relaxation time, the response to this impulse will vary from a slight deformation of the drop (which damps out in a few oscillations) to total breakup at the higher beam energies. For a drop which is still in a highly circulating state, a much smaller perturbation will usually cause total drop breakup into much smaller droplets.



a b c

Figure 4. Drop-Laser Beam Interaction at Several Heights Above the Drop Maker. Shown are (a) both parts being affected when the laser beam is focused one millimeter above the dropper tip, (b) both still strongly affected with laser moved up to two millimeters above tip, and (c) at a height of four millimeters the smaller drop passes through unaffected after the larger is still strongly perturbed

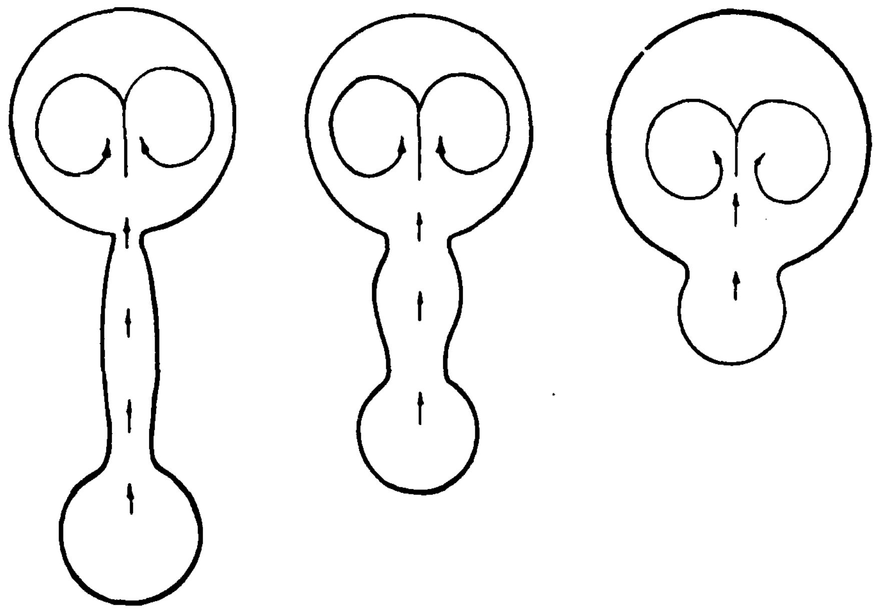


Figure 5. Schematic of Drop Evolution and Hypothesized Circulation

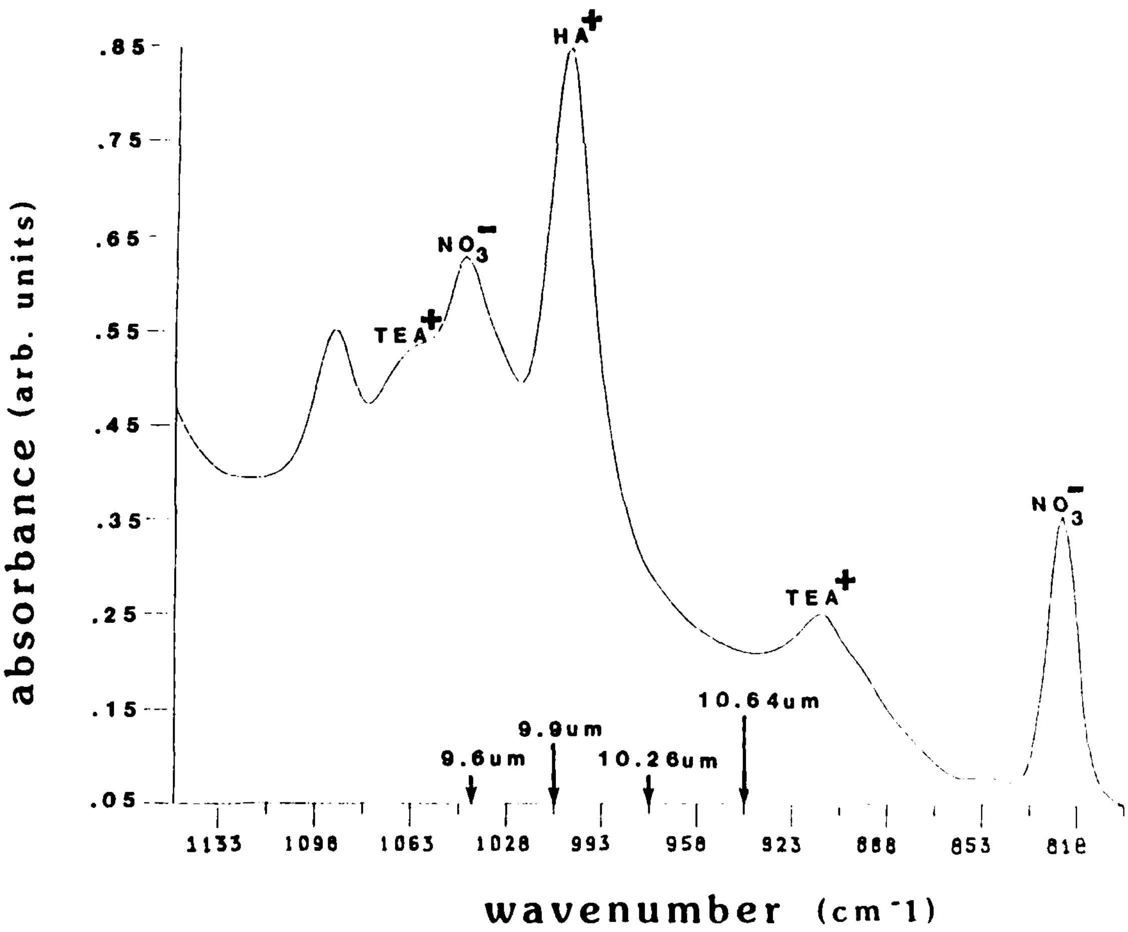


Figure 6. Infrared Absorption Spectrum of LP 1845

The relationship of these observations to the earlier reported variations in propensity to microexplode is clear but still only qualitative. A drop with significant circulation should carry heat to the interior much more quickly than from simple conduction and thus more rapidly attain the necessary internal temperature for explosion.

This study also has implications in other aspects of the LP spray phenomenology. The drops formed from liquid jet breakup are likely to possess at least some initial internal motion similar to that believed to be causing the present effects. Since this results in less drop stability, subsequent interdrop collisions will likely result in the further breakup of drops and formation of a rapidly decreasing size distribution. Thus any study of drop-drop collisions, for example should consider the relevance of measurements made after times for relaxation of the drops after formation. Of course, good estimates of the degree of internal excitation in drops formed from liquid jet breakup would be as invaluable as they are likely to be difficult to obtain. The importance of obtaining good values of liquid parameters such as surface tension and viscosity over the relevant temperature range is clear.

The significance of these observations to the possible use of this laser for heating suspended or levitated drops is not strongly encouraging. Although these drops can clearly be held long enough to relax any internal motion, the perturbation of a typical drop at only moderate laser light flux suggests that uniform illumination from multiple directions may be necessary to maintain the drop's geometric integrity as well as for heating considerations. The observations of vapor from the drops in the low energy density colinear configuration indicate that the absorption of laser energy in the focused beam probably does not involve a nonlinear process.

As can be seen in the Figure 3, the potential for some interesting studies on the effect of deposition of the laser energy in different components is strongly suggested.

V. CONCLUSION

The effect of laser irradiation of liquid propellant drops formed by a piezoelectric device has been studied. The drops show strong evidence of internal circulation which has a substantial effect on the stability of the drop following the perturbation caused by the laser beam. Drops with more circulation undergo breakup much more readily than those without. The implications for the study of drop-drop collisions and heating of drops for ignition studies are discussed.

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